Evaluating Indoor Air Movement in Student Residential Building Using Cross Ventilation Strategies

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***Abstract*— Natural ventilation is among the essential aspects to be considered to provide an acceptable indoor air quality (IAQ) in building designs. A proper ventilation process helps to deliver fresh air and expels heat and indoor pollution. Majority of people spend almost 90% of their lives inside building. Hence, the internal air pollution is persistently reported to be relatively 2 to 5 times higher than the outdoor pollution. Therefore, the research aims to investigate the potential of cross ventilation in improving indoor air movement in the student residential building. The study will provide an opportunity to examine indoor airflow conditions in a case study building by conducting model testing using Computational Fluid Dynamic (CFD) simulations. Data from the simulations will help to identify air movement conditions and subsequently propose improvement strategies to the premises. The proposed improvements might help the building management to provide better design upgrades to enhance natural cross ventilation performance by providing an appropriate configuration of openings in which a sustainable living environment can be established. The results confirmed that indoor air movement is greatly influenced by the type of opening and position with center pivoted window panels both vertically and horizontally allow more air moving into the room compared to side hinged windows.**

Keywords— Passive design strategies; cross ventilation; CFD simulation

I. Introduction

Indoor environment play an important role in a building design as its affects living condition, health and quality of life of the occupant. However, when majority of people spend almost 90% of their lives inside building, internal air pollution is persistently reported to be relatively 2 to 5 times higher than outdoor pollutions [1]. This scenario is worsening if there is insufficient ventilation in the building due to the building design or activities by the occupants. Poor ventilation in building design can contribute to problems of energy (Energy & environmental crisis), social (social problem), economy (increase cost of living) and health (low productivity) [2]. In order to provide an acceptable indoor air quality (IAQ) in building designs, natural ventilation is among the important aspects to be considered. A good ventilation process helps to deliver fresh air and expels heat and indoor pollution. This is the fundamental of green building concept where natural ventilation provides better indoor air quality (IAQ) and thermal comfort to their occupants while reducing building's energy consumption.

This scenario mentioned in the previous section is similar to students who stay in hostels which spend a lot of their time indoors especially after classes on weekdays and weekends. The function of student residential is to provide a supportive learning environment which will help to increase the students' success and achievement in the academic. Therefore, student residential buildings with a good level of indoor environmental quality can improve individual performances and concentration in aspect of learning. Thus, good indoor environment quality level is necessary to their wellbeing.

There are numerous researches in the literature focusing on natural ventilation in residential such as single and double storey terrace houses, high rise flats and apartments. These researches have listed measures that can be used to enhance the natural ventilation specifically for residential building. However, there are a few studies on student residential buildings were conducted in Malaysia which normally has the occupancy from 2 to 4 students per room. The findings of these researches are generally on natural ventilation provide better indoor thermal condition, the importance of indoor thermal condition in contributing to occupants indoor comfort satisfaction and how natural ventilation influence energy performance.

However, studies conducted on the indoor environment condition for student residential building with occupancy more than 4 students per room is scanty. Therefore this study aim to investigate the effect of opening configurations in evaluating indoor air movement in student residential building using cross ventilation approach.

To achieve this aim, the following objectives were derived:

- To identify the types of opening configurations used for cross ventilation.
- To describe the current indoor air movement condition in a case study building by means of Computational Fluid Dynamic (CFD) simulation.
- To evaluate the influence of different opening configurations in improving indoor air movement by means of Computational Fluid Dynamic (CFD) simulation.

A review of studies on natural ventilation enables to ascertain the most effective window opening configurations for cross ventilation approach. The installation of a wall-mounted center pivoting window in a bedroom significantly improves the indoor air quality by increasing the efficiency of the natural ventilation [3]. Windows in an upward position (45◦), could produce noticeable improvements in air velocity and comfort levels. Simulation studies have also shown that pivot windows at a 45◦angle have a more significant effect on indoor air velocity than those at 30◦ [4]. A study also concluded that certain opening position can help to boost the wind-induced ventilation performance especially in a densely packed area as in urban region. Higher air flow rate is observed when the inlet on the windward façade is located near the roof regardless of any outlet position on the opposite wall [5].

II. METHODOLOGY

Computational Fluid Dynamic (CFD) Simulation

This study simulates indoor air movement in the existing case study room condition and six sets of test models. The dimensions of existing case study room are 7.5 m (L) x 5.4m (W) x 3.1m (H). Figure 1 shows the layout of case study room. 6 opening configurations were introduced to the test models with different window types and louvers opening on existing partition and walls. Table 1 indicates the test models opening configurations.

The simulation is done by creating 3D model of a typical case study room using Autodesk Revit. These test models than exported to Autodesk Simulation CFD where a wind tunnel simulation is conducted. There are three boundary conditions to define the inputs of the simulations, these conditions are:

- Wind Velocity; used as an inlet boundary condition
- Pressure; used as an outlet condition
- Slip/Symmetry; this condition causes the fluid to flow along a wall instead of stopping at the wall, which typically occurs along a wall.

Figure 2 shows the boundary conditions used in the wind tunnel simulation.

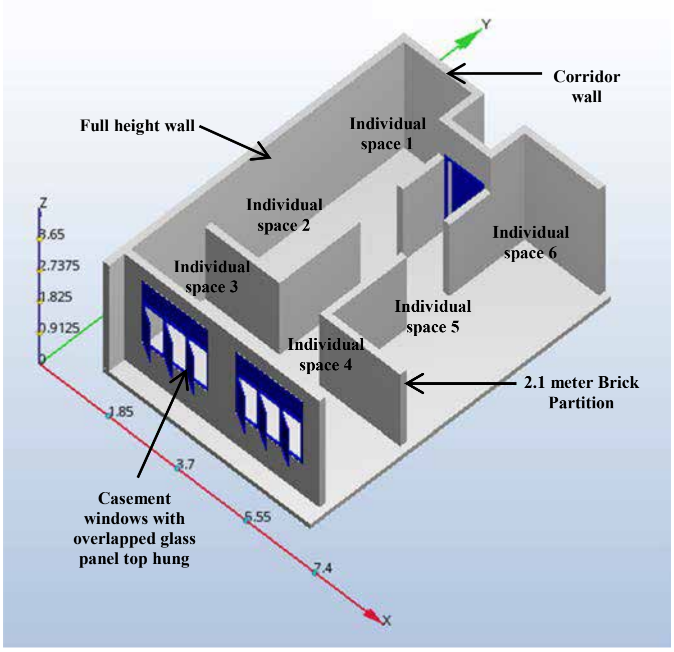

Fig. 1. A typical case study room layout

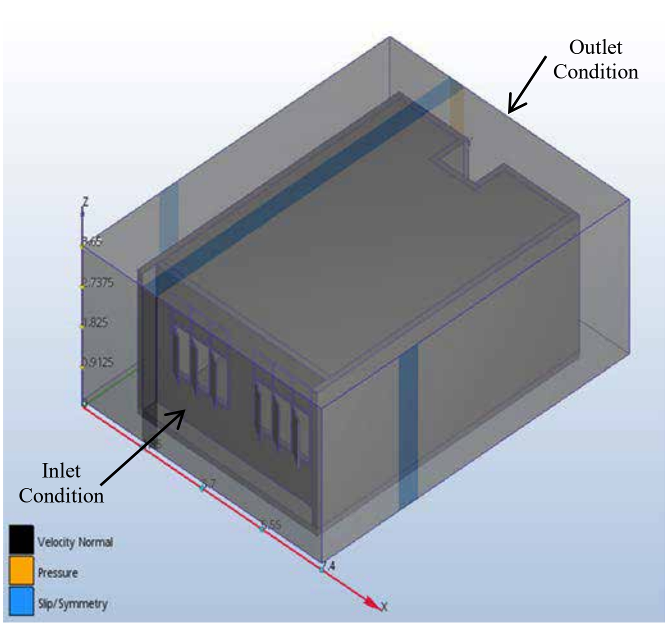

Fig. 2. Boundary conditions

TABLE 1. OPENING CONFIGURATION

No	Code	External Wall	Internal Partition	Coridor Wall
1	TM1	Main Window - Side Hinged Casement Window 30 deg openable Upper Window - Top Hung 45 deg	0.6m x 1.2m louvres @ 1.2m High to bottom sill	0.6m x 1.2m louvres @ 2.1m High to bottom sill
2	TM2	Main Window - Side Hinged Casement Window 30 deg openable Upper Window - Top Hung 45 deg	0.6m x 1.2m louvres @ 1.2m High to bottom sill	0.6m x 1.2m louvres @ 300mm High to bottom sill
3	TM3	Main Window - Horizontal Center Pivoted Casement Window 30 deg openable Upper Window - Top Hung 45 deg	0.6m x 1.2m louvres @ 1.5m High to bottom sill	0.6m x 1.2m louvres @ 2.1m High to bottom sill
4	TM4	Main Window - Side Hinged Casement Window 30 deg openable Upper Window - Top Hung 45 deg	0.6m x 1.2m louvres @ 1.5m High to bottom sill	0.6m x 1.2m louvres @ 300mm High to bottom sill
5	TM5	Main Window - Vertical Center Pivoted Casement Window 30 deg openable Upper Window - Top Hung 45 deg	0.6m x 1.2m louvres @ 1.5m High to bottom sill	0.6m x 1.2m louvres @ 2.1m High to bottom sill
6	TM6	Main Window - Vertical Center Pivoted Casement Window 30 deg openable Upper Window - Top Hung 45 deg	0.6m x 1.2m louvres @ 1.5m High to bottom sill	0.6m x 1.2m louvres @ 300mm High to bottom sill

The reference wind velocity is 1.8 m/s and was based on records of mean surface wind speed of February 2015, 2016 and 2017 for Ipoh. Each window configuration openings were set to open at 30 degree for safety purposes. A typical louver panel with size of 0.6m x 1.2m with 30 degree aluminium fin angle were used at internal partition and corridor wall. 3 points of measurement were taken on each test model at the centre of individual spaces approx. 1.2 meter above the floor. These points measures the wind velocity perceived by occupants at each spaces. The results were then referred to Malaysian Standards MS1525:2014 for comparison. Table 2 display impact of air speed to occupant sensation [6]. The aim of study is to evaluate the influence of different opening configurations and layout in improving indoor air movement using cross ventilation strategies. It will not include studies on thermal comfort or energy performance.

TABLE 2. IMPACT OF AIR SPEED ON OCCUPANTS

Air speed (m/s)	Mechanical effect	Occupant sensation
≤0.25	Smoke (from cigarette) indicates movement	Unnoticed, except at low air temperatures
0.25 - 0.5	Flame from a candle flickers	Feels fresh at comfortable temperatures, but draughty at cool temperatures
0.5 - 1.0	Loose papers may be moved. Equivalent to walking speed	Generally pleasant when comfortable or warm, but causing constant awareness of air movement
1.0 - 1.5	Too fast for deskwork with loose papers	Acceptable in warm conditions but can be from slightly to annoyingly draughty
> 1.5	Equivalent to a fast walking speed	Acceptable only in very hot and humid conditions when no other relief is available. Requires corrective measures if comfort and productivity are to be maintained

III. RESULTS AND DISCUSSIONS

Fig. 3 showed section view represents the result of CFD simulation for existing case study room. It is observed that with the existing window opening the average indoor air velocity of the room is between 0 m/s and 0.2 m/s. In this condition the velocity is considered low and does not achieve the acceptable range for thermal comfort as stipulated in Table 2. This also confirms the several complaints received by the resident warden by students claiming the rooms are thermally uncomfortable. A brief observation was conducted on one of the room and it was found out that the room is stuffy and has foul odour due to lack of air movement.

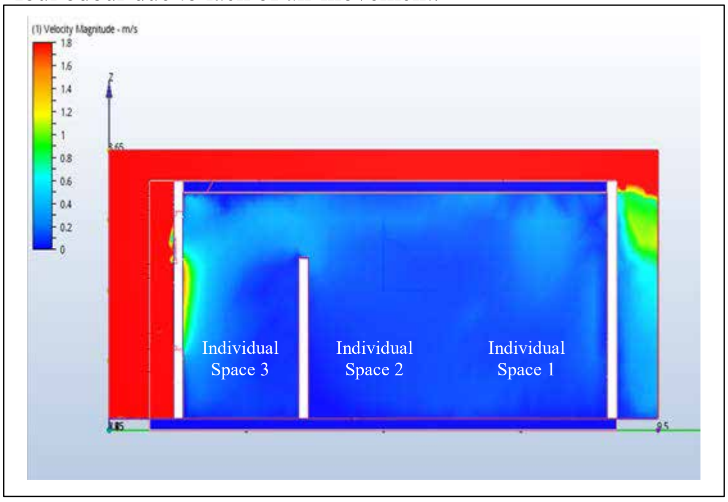

Fig. 3. Section view of indoor air movement in the existing case study room

Section views in Fig. 4, 5 and 6 represents indoor air movement behaviours in TM1, TM3 and TM5 respectively. Wind velocity recorded inside these test models at measuring points is between 0.1 m/s and 1.8 m/s. It is observed that the highest volume of air entering from the windows is in TM6 compared to TM2 and TM4. The high air velocity upon entering the main window appears moving up above the living zone and remains near the ceiling before exiting out through louvers located 2.1 meter from the floor. Velocity at areas behind the internal partition is observed to be low and stagnant. It can be concluded with the results that indoor air movement in TM1, TM3 and TM5 are generally higher on upper portion of the room compared to occupant living zone.

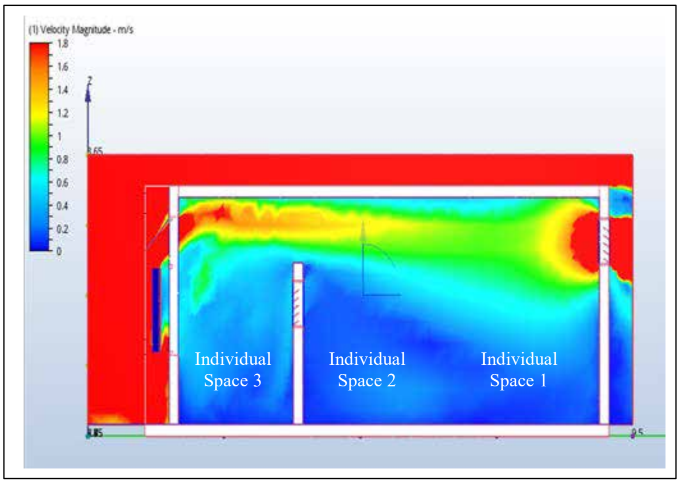

Fig. 4. Section view of indoor air movement in TM1.

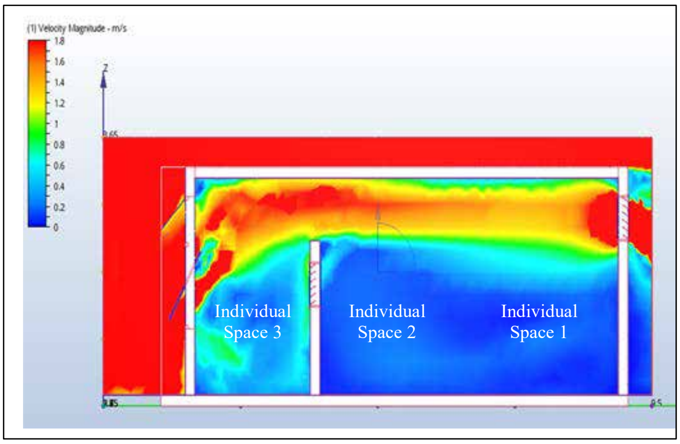

Fig. 5. Section view of indoor air movement in TM3

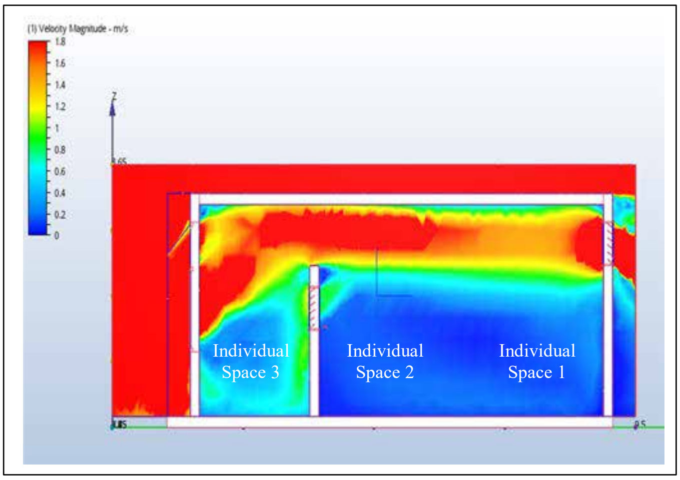

Fig. 6. Section view of indoor air movement in TM5.

Fig. 7, 8 and 9 showed the graph of wind velocity at measuring points in TM1, TM3 and TM5 respectively. In TM1 wind velocity recorded at centre of individual space 1, 2 and 3 was 0.32 m/s, 0.13m/s and 0.6 m/s respectively. In TM3 air velocity recorded at similar measuring points were 0.2 m/s, 0.18 m/s and 0.2 m/s respectively while in TM5 air velocity recorded were 0.35 m/s, 0.2 m/s and 0.4 m/s respectively. From the results it showed that the air velocity at individual space 2 and 3 is between 0.13 m/s and 0.2 m/s while individual space 1 which located facing the main window has higher air velocity. According to Table 2 occupant sensation at individual space 1 is feeling fresh at comfortable temperature while occupant at individual space 2 and 3 shall experience unnoticed air movement. Fig.10 shows the summary of indoor air movement in TM1, TM3 AND TM5.

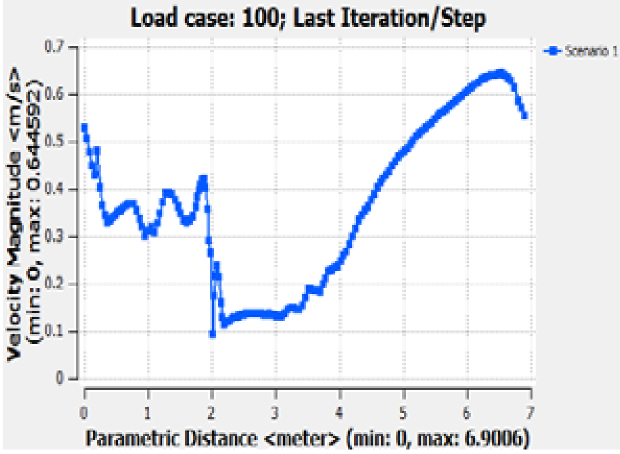

Fig. 7. Air velocity across TM1 at 1.2 meter

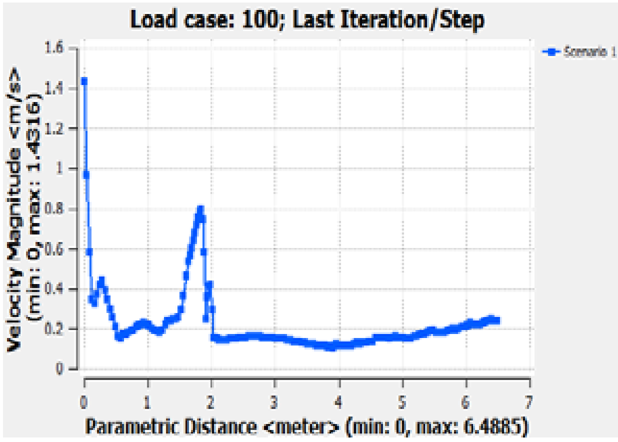

Fig. 8. Air velocity across TM3 at 1.2 meter.

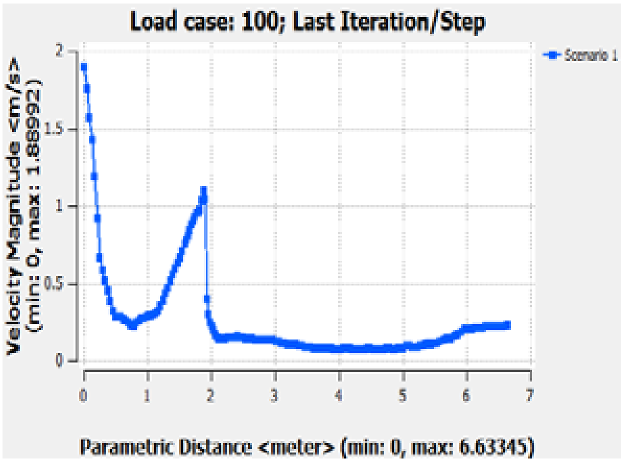

Fig. 9. Air velocity across TM5 at 1.2 meter

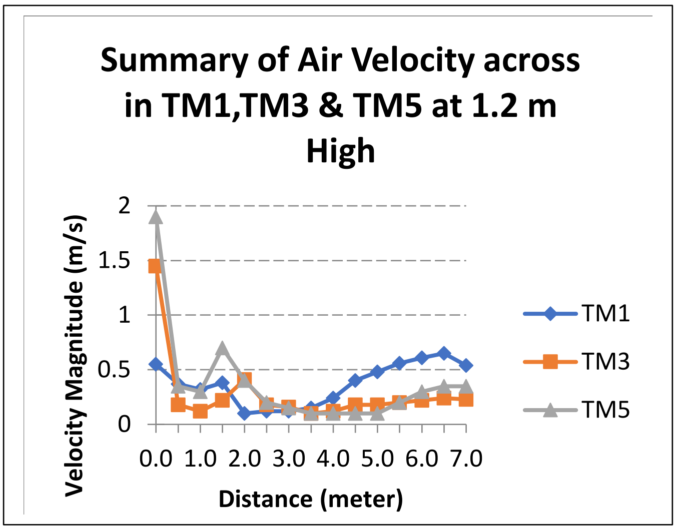

Fig. 10. Summary of TM1, TM3 and TM5

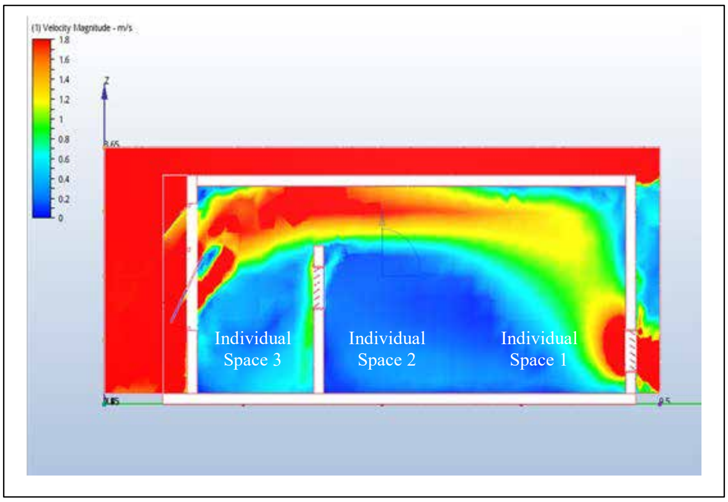

Fig. 12. Section view of indoor air movement in TM4

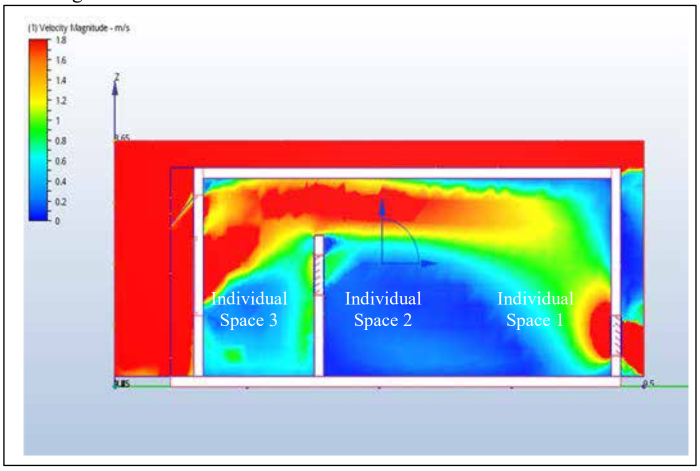

Fig. 13. Section view of indoor air movement in TM6

Fig. 11, 12 and 13 reveal indoor air movement behaviours in TM2, TM4 and TM6 respectively. Wind velocity recorded inside these test models at measuring points is between 0.1 m/s and 1.8 m/s. It is observed from the figures that generally there is a high volume of air entering from the windows in TM4 and TM6 compared to TM2. Similarly with the previous sets of test models, the high air velocity upon entering the main window appears moving up above the living zone nearer to the ceiling but descent down towards louvers located near to the floor while velocity at areas behind the internal partition is observed to be low and stagnant. Between these test models, TM6 showed the highest indoor air velocity intake compared to TM2 and TM4.

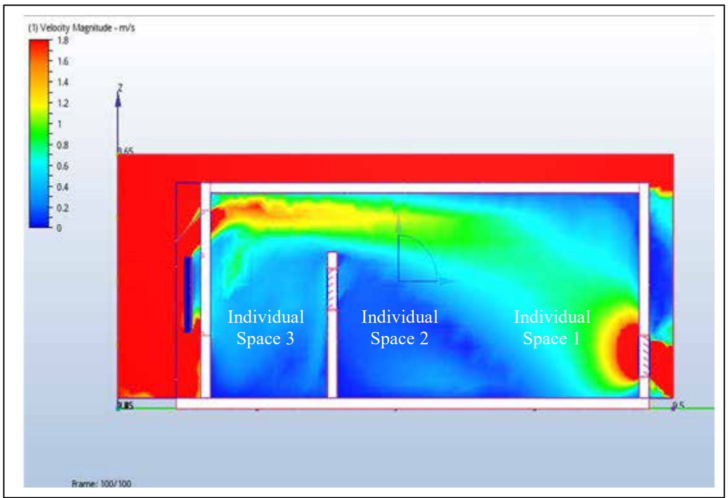

Fig. 11. Section view of indoor air movement in the TM2

Fig.14, 15 and 16 showed the graph of wind velocity at measuring points in TM2, TM4 and TM6 respectively. In TM2 wind velocity recorded at centre of individual space 1, 2 and 3 was 0.35 m/s, 0.15m/s and 0.78 m/s respectively. In TM4 wind velocity recorded at similar measuring points were 0.35 m/s, 0.15 m/s and 0.83 m/s respectively while in TM6 wind velocity recorded were 0.4 m/s, 0.2 m/s and 0.8 m/s respectively. From the results it showed that the air velocity at individual space 1 and 3 is between 0.35 m/s and 0.8 m/s while individual space 2 which located at the centre of the room has less than 0.25 m/s. According to Table 2 occupant sensation at individual space 1 and 3 will feel fresh and generally comfortable while occupant at individual space 2 shall feel unnoticed air movement. Fig.17 shows the summary of indoor air movement in TM2, TM4 AND TM6.

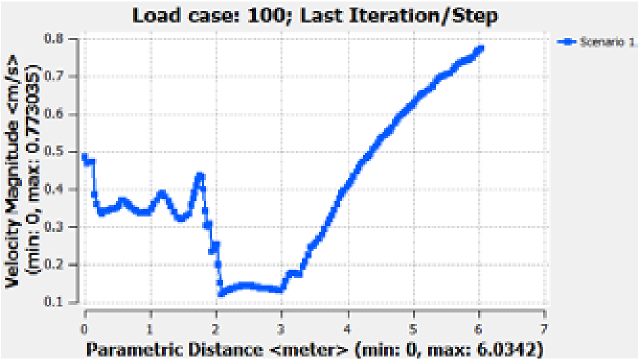

Fig. 14. Air velocity across TM2 at 1.2 meter

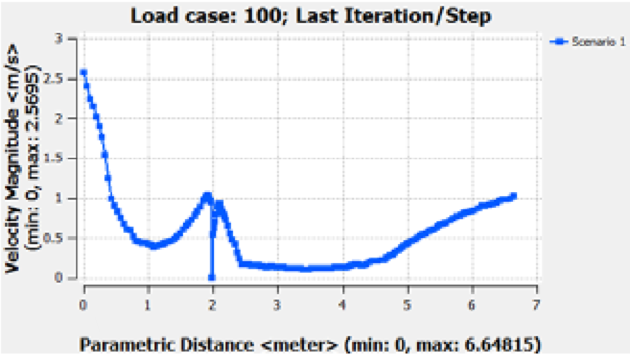

Fig. 15. Air velocity across TM4 at 1.2 meter

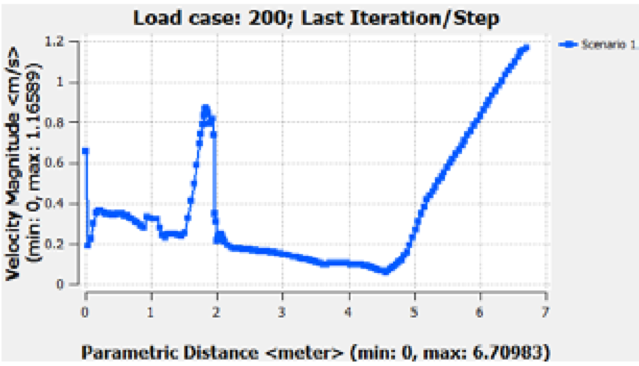

Fig. 16. Air velocity across TM6 at 1.2 meter

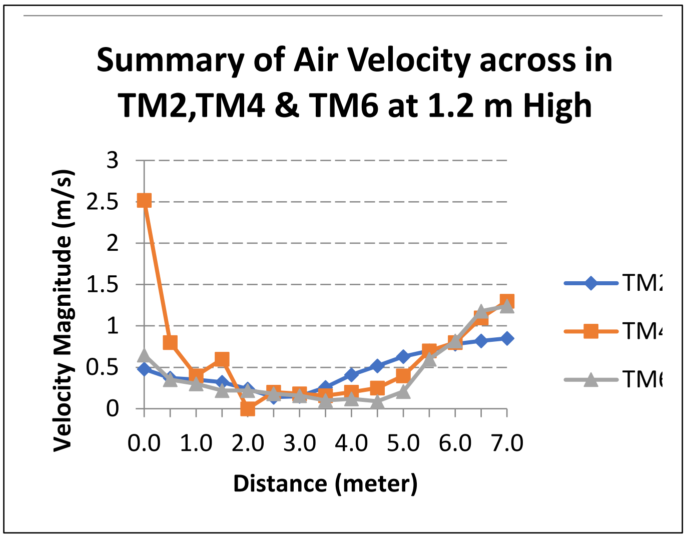

Fig. 17. Summary of TM2,TM4 and TM6

IV. CONCLUSION

The study results show that there are significant thermal discomfort conditions inside the existing study model, due to the lack of air circulation within the living zone. By using the findings from previous researches, the effectiveness of different opening configuration in the test models is obviously seen in the results. The findings confirmed that indoor air movement is greatly influenced by the type of window opening and the position of louvers panel on the opposite wall. Center pivoted window panels both vertically and horizontally allow more air moving into the room compared to side hinged windows. However, individual spaces at the center of the room still experience low velocity of air movement. Although louvers is introduced to internal partition as the opening to allow air circulation, the amount of air movement in the living zone still did not achieve the acceptable range of air velocity for thermal comfort which is between 0.25–1.5 m/s. Further studies on other variations of openings are recommended to enhance natural cross ventilation for thermal comfort.

ACKNOWLEDGMENT

The authors would like to thank student residential building management at Politeknik Ungku Omar Ipoh Perak for their permission to carry out research for this paper.

REFERENCES

[1] K. Hess-Kosa, *"Indoor Air Quality: Sampling Methodologies"*, CRC Press, Florida, 2002.

[2] Razak, S. A., "*Possibilities of using Void to Improve Natural Cross Ventilation in High-rise Low Cost Residential Building*"(Doctoral dissertation, Thesis), 2004

[3] A.A Jamaludin,, H. Hussein,A.R. Mohd Ariffinand N.Keumala, *"A Study On Different Natural Ventilation Approaches At A Residentialcollege Building With The Internal Courtyard Arrangement,"* Energy and Buildings 72 (2014) 340–352

[4] A.Aflaki, N. Mahyuddin, Z. Al-Cheikh Mahmoud and M.R. Baharum, "*A Review On Natural Ventilation Applications Through Building Fac, Adecomponents And Ventilation Openings In Tropical Climates,"* Energy and Buildings 101 (2015) 153–162

[5] N.F.M. Kasim, S.A. Zaki, M.S.M. Ali, N. Ikegaya, A.A. Razak*" Computational Study on the Influence of Different Opening Position on Wind-induced Natural Ventilation in Urban Building of Cubical Array,"* Procedia Engineering 169 (2016) 256 – 263

[6] Malaysian Standard 1525:2014, *"Energy Efficiency and Use of Renewable Energy For Non Residential Buildings-Code Of Practice (Second Edition)",* Department Of Standards Malaysia, 2014.